PB-215 021

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Public Health Service
Cincinnati, Ohio

1938

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PROGRESS AND POSSIBILITIES IN SEWAGE TREATMENT RESEARCH,*

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The title of this paper may be somewhat misleading because it is not the intention to present an exhaustive review of developments in the field of sewage treatment and certainly not to prophesy concerning the extent or direction of improvements or of revolutionary changes in our present methods of disposal. It is desired, however, to focus attention on some phases of research that are being slowly developed and the implications of which, when more clearly understood, may be of some assistance in perfecting biological processes that have experienced lapses in efficient performance resulting from obscure causes.

There are two principal ways of conducting scientific research on any problem, the experimental or trial method and the fundamental or basic research procedure. As applied to sewage treatment, by the first method a wide range of composite experiments with similar materials of varied groupings is conducted to determine the combination that works best to produce the desired result, without the necessity of exploring completely the possibilities or characteristics of each individual component. In the latter procedure, the purely scientific approach is employed by determining the unknown underlying physical and other properties of each individual constituent of the problem and the laws under which these

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(*) Prepared for presentation Texas Water Works Short School, February 18, 1938.

separate factors combine or react with each other. There is thus built up by this latter method a fund of knowledge from which we can deduce the course of reactions that may be expected to result from definite combinations or mixtures of substances either chemically or biologically active when brought together under controlled conditions.

These two methods of approach are usually complementary. The basic research procedure is usually more general and comprehensive though indirect in relation to the solution of any single, practical problem and for this reason is sometimes termed pure research, having no specific, limited application, whereas the experimental method undertakes direct observations of the combination under study with only such consideration of the individual components as is immediately essential. For example, Edison, employing the experimental approach, in the invention of the electric light tried out an extensive array of filament materials until he found a satisfactory one, rather than first determining all the chemical and physical properties of each, from which he could have deduced that a certain kind of carbon would fill the requirements.

This trial and error method of research has far outdistanced the basic research method in the development of sewage treatment processes. This is particularly true of the biological systems that have reached an apparently high degree of efficiency regardless of the fact that comparatively little is known of the role or characteristics of the biological agents that bring about coagulation, absorption, oxidation or precipitation of the objectionable

organic constituents of sewage. In the sprinkling filter, for example, a device has been perfected experimentally that will oxidize dissolved organic matter rapidly, will not clog or give off offensive odors, will reduce enormously the bacterial content and will produce a consistently satisfactory effluent with comparatively little attention. But of the agencies that are responsible for these profound changes in the liquor as it passes through the six or more feet of filtering medium, specific knowledge has been lacking. Concerning the definite functions of the varied groups of protozoa and other plankton forms, insect and other larvae, and even of the zoogleal slime coating of the filter stones, our information is sketchy and incomplete. It seems reasonable to suppose that if this biochemical mechanism were more thoroughly understood, even more favorable environmental or other conditions might be provided whereby the rates and efficiency of these reactions could be still further improved.

Many such fundamental problems are presented in almost every phase of operation of biological treatment plants. It is only recently that we have had any knowledge of the amount, if any, of dissolved oxygen normally existing in aeration tanks or even of a method for determining this constituent. We have not known even, whether or not oxygen is soluble in sewage liquors to the same extent that it is in clear water, although the economics of the whole activated sludge process is dependent upon this knowledge. Furthermore, there is no guide as to the rate at which this dissolved oxygen is used up in any of these oxidation processes whether it be the aeration tank, the sprinkling filter, the contact filter or

the sand filter. It would seem that we have reached the point where fundamental research on these matters should be advanced to supply the necessary foundation for further progress in the art and even for advancement of the experimental or trial and error method of research.

Progress in Practical Research.

However, it is not the intention to point out all the deficiencies in our knowledge of sewage treatment biology, chemistry and operation but rather to mention some of the advances that have been made in practical experimentation and to discuss somewhat more fully some of the phases of research that are throwing a little light on the fundamental motivating agencies that are operating in the natural purification processes of polluted water and sewage.

There is no need to review in detail the steady progress that has been made in the applied art of sewage treatment during the last decade or two. This progress is ably presented by various authors of reviews, trends and developments in sewage disposal. Among these may be mentioned the annual summaries of the Committee on Research, Federation of Sewage Works Associations(1), of The Surveyor(2), of Garner(3), and of the Committee on Sewage Disposal of the American Public Health Association.(4)(5)(6)(7) Other articles in the technical press including those by Emerson(8), G. Berry(9), Donaldson(10), Eddy(11)(12), Shenton(13), Rudolfs(14)(15)(16), Garner(17)(18), O'Shaughnessy(19), Howson(20), Hyde(21)(22)(23), Pearse(24), Imhoff(25)(26), Watson(27), Robinson(28), Greeley(29), A. E. Berry(30), Bach(31)(32), Cooke(33)

and Wardley[34], supply detailed information concerning the advances in practice and research on all phases of sewage disposal. The progress discussed in these reviews has developed largely through experimentation and expansion into full scale operating procedures. Among the more recent milestones of this progress may be noted:

1. Development and improvements in the activated sludge process, including the reduction in aeration time and volume of diffused air required, partial treatment ahead of sprinkling filters and a variety of procedures for replenishing the dissolved oxygen in the sludge-sewage liquor.

2. The return of chemical precipitation induced largely by improved mechanical devices for chemical dosing and mixing, and sludge removal and disposal.

3. Extension of the use of chemicals for odor and gas control, coagulation, precipitation, disinfection and for sludge dewatering and digestion.

4. Changes in sprinkling filters to increase their capacity such as forced aeration, pretreatment of influents, recirculation and series operation.

5. Improvement in methods of sludge handling and disposal including dewatering, digestion with gas production for power operation and heating, incineration and fertilizer manufacture.

These and other improvements have given rise to a wide variety of mechanical devices to reduce operating labor costs so that modern plants are becoming more and more complex in all their parts.

Progress in Basic Research.

In comparison with the rapid strides in experimental and full scale plant operation, the increase in our knowledge of the fundamentals of biological oxidation has been painfully slow. It is interesting, however, to review some of these developments as research studies have disclosed them.

The process of natural purification in polluted streams is primarily a biological one in which organic matter is broken down to carbon dioxide and water and nitrogenous products are broken down to ammonia, nitrites and finally to nitrates. Dissolved oxygen is used in the process during the multiplication of bacteria which use the organic matter as food and function as the active reducing agents. Under natural conditions - including sewage disposal by dilution - this process is severely limited by various restrictions such as the low dissolved oxygen capacity and slow reaeration rate of water, the dilute solution of organic matter and the consequent difficulty of bacterial contact with food material, and changes in environmental conditions such as temperature, light and toxic substances, to which all minute aquatic life is sensitive. These limiting conditions force the progress of biochemical oxidation under natural conditions into a comparatively narrow groove, which we measure roughly by the biochemical oxygen demand test.

The interpretation of this test signifies in effect that when polluted water is maintained at a constant temperature of 20°C. in an aerobic condition and the first stage biochemical

oxygenation of the organic matter is allowed to proceed normally, the rate of oxidation will follow a fixed mathematically defined course such that 68 per cent of the oxidizable carbonaceous material will be satisfied in 5 days and 99 per cent in 20 days. However, if this normal progress of biological growth is prevented or disturbed, the test becomes unreliable. Some of the more common factors which interfere with this biochemical reaction are: (1) improper seeding of the sample at the start of the test with the complex mixture of biological forms, both bacteria and plankton which are normally present in sewage and most river waters; (2) presence of some toxic material in the sample under test; (3) insufficient dissolved oxygen supply to meet the requirements of the aerobic organisms throughout the entire period of observation, and (4) perceptible fluctuation of the temperature of the sample during the incubation period. It is highly essential to observe these precautions, therefore, if accurate results are to be obtained.

To the extent that such restrictions as indicated above are removed, this rate of oxidation can be speeded up and this is what we do more or less imperfectly in actual practice in all of our processes for the complete treatment of sewage which depend upon biological activity for the reduction and removal of dissolved organic materials present in the liquor. Our efforts to provide effective purification by contact filters, sand filters, sprinkling filters, and all forms of aeration devices including the various activated sludge procedures have this objective in view. These devices provide means for maintaining a reserve dissolved oxygen supply in the liquor and conditions for the development of high concentrations of bacteria by providing for contact of the active bac-

terial cells with highly concentrated liquid food. It seems reasonable to suppose that more concrete knowledge of the factors that stimulate or retard these biological functions might be of value in further practical application to sewage treatment processes. The Public Health Service, at its Cincinnati laboratory, has been engaged for a number of years in basic research of this character.

It has been shown that there is a quite definite relation between maximum bacterial numbers that will grow in a liquid medium and the concentration of the available food supply(35) and that between the limits of the minimum required for good growth and the maximum amount consistent with maintenance of aerobic conditions, the upper bacterial limit will not increase quite so rapidly as the increase in concentration of food. This would seem to indicate that space requirements act as a deterrent to the free multiplication of bacterial cells as the upper limiting density is being approached. It has been demonstrated also that where no predatory plankton are present, the bacteria quickly reach a maximum number after which little further increase occurs.(36) During this multiplication period dissolved oxygen is used at a rapid rate but when cell reproduction ceases, no further oxygen is required. However, when bacteria and animal plankton are grown together in the same culture the bacteria never reach their limiting numbers and the use of oxygen continues over a longer period until the food material is exhausted, that is until the organic material is oxidized. Inasmuch as the plankton by themselves consume very little oxygen, it appears that their chief function in the oxidation process is to keep the bacterial population below its limit-

ing number, thereby stimulating multiplication and consequently completing the oxidation of the available organic material. Other methods of reducing bacterial concentration such as sedimentation with a coagulant, by chlorination, filtration or pasteurization were shown to have the same stimulating effect on bacterial multiplication and resulting continued oxidation of the dissolved organic matter.

If now the limitations of decreasing dissolved oxygen supply and of reducing food supply are removed, that is if the bacterial culture in the liquid medium is aerated continuously and additional food is periodically added, an artificial condition is created permitting higher concentrations of bacteria to grow and effecting more rapid oxidation of organic matter. If in addition, bacterial cells are periodically removed by one procedure or another so that new cells can develop in their place, we have in effect an artificial process for biochemical oxidation more efficient than the natural purification one.

As to the species or types of bacterial cells that will best perform these oxidizing functions not a great deal is known. In general it is found that the extent of oxidation observed varies directly with the number of species present which may be explained by reason of the fact that different species doubtless use slightly different food materials and the greater the number of kinds of bacteria acting, the larger the proportion of the entire organic matter that is attacked. In an effort to discover some types of bacteria that might be active in this oxidation process, Butterfield[37]

has isolated, repeatedly, a predominant zoogleal form from flocs of good activated sludge obtained from a number of widely different sources. This organism when inoculated into a liquid medium, either of clear synthetic sewage or of sterile natural sewage, under continuous aeration produces a sludge with properties closely akin to those of activated sludge. It develops very rapidly in numbers, using large amounts of oxygen, it has the property of forming huge clumps or flocs of bacterial cells which settle out readily and it reduces the 5-day B.O.D. of the medium as much as 80 per cent in three hours.

The characteristics of this zoogleal organism are of interest in connection with the activated sludge process. By clumping in large massed colonies in the liquid medium or sewage liquor with sufficient tenacity to withstand the currents created by agitation, a zoogleal floc is provided which provides a better contact for larger numbers of bacteria with highly concentrated food as these flocs circulate through the aeration tank. Experimental evidence indicates, also, that the protoplasm of these flocs has definite adsorption properties for the organic food material by which means it is made available for the growth of new individual cells. Hence in floating about, the floc acts as a strainer or filter of dissolved organic matter in the sewage liquor. By this same process a considerable volume of coarser suspended matter is enmeshed in the floc bodies and carried down when the floc settles out. This clumping and settling out process obviously supplies the additional requirement of constantly diminishing the upper limiting number of cells suspended in the liquid medium, thereby permitting

the generation of new cells, in the formation of which more organic matter is oxidized. And because it has this particular property doubtless is the reason why it is the predominant bacterial species in good activated sludge.

Whatever the role of this species of bacteria in the activated sludge process, it has proven a valuable tool for further exploration of some of the phenomena of biochemical oxidation under controlled conditions because it grows readily in a strictly reproducible medium, oxidizes the contained organic matter at rates high enough to permit of ready measurement of the amounts of oxygen used at frequent time intervals, and forms sludge that can be removed periodically, thereby automatically providing for continued cell multiplication without the need of bacteria eating plankton or other artificial methods of cell reduction. Moreover, the flocs composed of closely packed bacterial cells evidently have the power of adsorbing the organic material in solution, oxidizing it and synthesizing it into additional bacterial protoplasm.

Observations have shown, for example, that while in pure culture in a medium where all organic material is in solution, oxidation proceeds and the floc settles out, yet the supernatant generally will be turbid owing to the presence of large numbers of separate bacterial cells which have not formed flocs. If to such a sample, bacteria eating plankton are added and allowed to develop, these plankton apparently feed on the dispersed cells and produce a bright clear supernatant liquor. This would seem to indicate that in the natural process the foraging plankton perform the addi-

tional duty of brightening the supernatant of final sedimentation tanks which otherwise would have been dull and even turbid in appearance. In fact, examination of various turbid effluents of our experimental plant has frequently shown that the turbidity is not dispersed inert material but living organisms in undue numbers, either bacteria or plankton, indicating that some operating condition has disturbed the proper biological balance in some part of the treatment process.

The observed rates of oxidation of organic material effected by this species of bacteria are also of interest because they throw some light on what happens in the activated sludge tank and probably in the sprinkling filter as well. The old concept of this process was that the organic matter in sewage liquors was adsorbed and stored by the floc or filter slimes and oxidized at the normal biochemical oxygen demand rate occurring in natural purification processes or in the B.O.D. test bottle in which the velocity constant k has a value of 0.1. However, where this oxidation is as much as 80 per cent completed in three or four hours as obtained with this pure culture, it is necessary to revise our theory of biochemical oxidation. In other words what we had previously supposed required seven days to accomplish, as in fact it does by the standard B.O.D. test, actually can be effected in three or four hours under artificially maintained conditions. Reasoning further, it indicates that biological oxidation can be accomplished, and doubtless is effected in properly functioning plants, in a few hours instead of during extended periods of time in days. In other words the activated sludge removed from the final sedimentation

tank is much nearer completely oxidized than previously had been supposed.

In another direction some explanation is afforded of what, for a better name, has been termed immediate oxygen demand in situations where dissolved oxygen is used rapidly in an organic solution in the presence of active biological processes. Such rapid oxygen withdrawal has been considered a strictly chemical phenomenon, in which the oxygen immediately combines with oxidizable constituents. In sewage and other organic containing liquors that are maintained aerobically, this does not appear to be the case necessarily, because in such case the reaction is not an instantaneous one but extends over appreciable periods of time and is evidently the result of biological forces similar to those occurring in the pure culture medium. The rates of such oxidation, although rapid, are readily determinable. Moreover, the extent of this rapid oxygen using power of activated sludge appears to offer a criterion of its ability to purify sewage and a basis for determination of its overall quality. This has been pointed out by Ruchhoft[38] as the result of extensive experiments which have shown that a good activated sludge has a definite optimum range in its oxygen requirements and that if such sludge is given either a too large or insufficient load of organic material or is improperly aerated, this active oxidation property is rapidly lost.

Equally interesting observations are now in progress concerning the best and quickest methods of building up an activated sludge with this zoogleal organism inoculated into a syn-

thetic sewage in which all of the food material is in true solution. Most rapid multiplication appears to occur if additional food is added to the mixture under aeration at intervals of a few hours when oxidation of the available supply has been over 50 per cent completed and yet before there is too great a depletion in the quantity of such food material. It is hoped that further experiments will supply more information on this point and others including the optimum dissolved oxygen content to be maintained, the proper rate of withdrawal of settled sludge from the aeration chamber, the effect on the sludge of resting in the sedimentation tank and the possibilities and best procedures for regenerating the sludge after its active oxidation powers have been impaired. Although such research must necessarily be carried on under controlled laboratory conditions the results are believed to be of interest in indicating the efficiencies that may be approached under actual conditions of full scale plant operation when the requirements of the active biological agents concerned are more fully satisfied.

It does not seem unreasonable to suppose that the exploration of the fundamental biology of the sludge digestion process would disclose some equally interesting facts. Little is known of the basic requirements and optimum environmental conditions of the organisms that function anaerobically to break down the organic constituents of sewage sludge into inert materials with the formation of gas. In fact, our knowledge of the species of organisms operating under these conditions is extremely limited. Now that the experimental method of research has demonstrated the prac-

ticability of sludge digestion and the valuable return in gas for power that may be obtained, more emphasis could well be placed on the fundamental principles underlying these reactions with the expectation of profitable returns. This is especially true now that the volumes of such sludges seem likely to be materially increased in a great many instances where garbage and sewage are mixed together and treated in the same plant.

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